Predicting the Evolution of Advanced Power Generation Technologies in Mobile Power Applications

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Overview

- Parallels between premium commercial and military mobile market needs
- The direction of commercial market driven technologies
- How these new technologies match up with military needs
  - Variable speed diesels
  - Microturbines
  - Fuel cells

Cummins Inc.

$1.4B Power Generation **$4.0B Engines** **$1.0B Filtration**

Stationary Power Markets

Standby / Peaking

Distributed Power

Residential

Small Remote
Telecomunications

Mobile Power Markets

Recreational Vehicle

Portable

Marine

Commercial

Rental

Premium Commercial Mobile Markets

Auxiliary Power (<15 KW)

RV

Work Vehicle

Trailer Power

Rental

Military Mobile Applications

Auxiliary Power

Man Portable

Trailer

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Evolution of Power Gen Technology

Engine Driven Gensets

Variable Speed Gensets

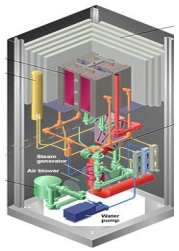
Hybrid Power and Battery

Larger military Variable Speed Engine-Driven Gensets

Switches & Switchgear

Micro-Turbine Gensets

Hybrid Electric Vehicle



Fuel Cell Power Systems

Mature *Emerging* *Future*

Noise Level vs. Technology

Noise dBA

85
84
83
82
81
80
79
78
77
76
75
74
73
72
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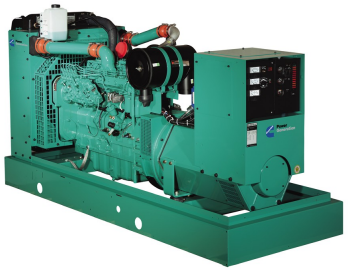


Open GenSet

85 dBA

Attenuated modular GenSet

Stage I 71 dBA

Stage II 67 dBA

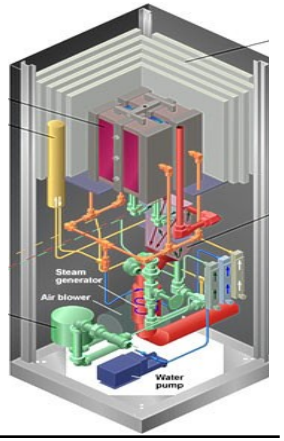
Microturbine or custom GenSet

73 dBA

63 dBA w/silencer option

Fuel Cell

59 dBA est..



Ref., commercial air conditioner is 61 d

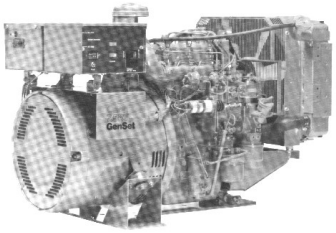
60 KW @ 7 Meters - Uninstalled

Mobile Diesel Noise Levels

Noise dBA

85
84
83
82
81
80
79
78
77
76
75
74
73
72
71
70
69
68
67
66
65
64

7.5 kWe Open Genset



Truck at Idle

12.5kW Quiet Diesel

7.5 kW Quiet Diesel

4kw- 3 Meters - Uninstalled

1980

2000

Importance of Attributes vs. Market

Power Generation

COMMERCIAL/DoD MARKET SYNERGIES	DoD Mobile	Commercial Mobile (<15kWe)	Commercial / Rental (>15kWe)
Power Density			
Size	H	H	L
Weight	H	H	L
Sociability			
Noise	H	H	M
Vibration	M	H	M
Exhaust Emissions	M	M	H
EMI	H	H	M
Performance			
Start time	H	M	H
Transient	H	M	M
Broad Application	H	L	H
Reliability	H	M	H
Ruggedness/Env/IR	H	L	M
Multi-Grade Fuels	H	L	M
Cost			
Initial	M	H	H
Fuel	H	L	M
Maintenance	H	M	H

High, Medium, Low

New Power Sources Technologies have Advantages and Challenges

- New technologies require a power systems design approach

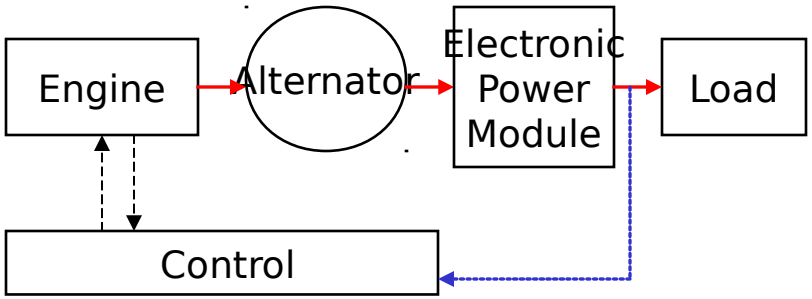
- All technologies considered that do not produce power with a synchronous alternator require output power inverters for frequency and voltage control.

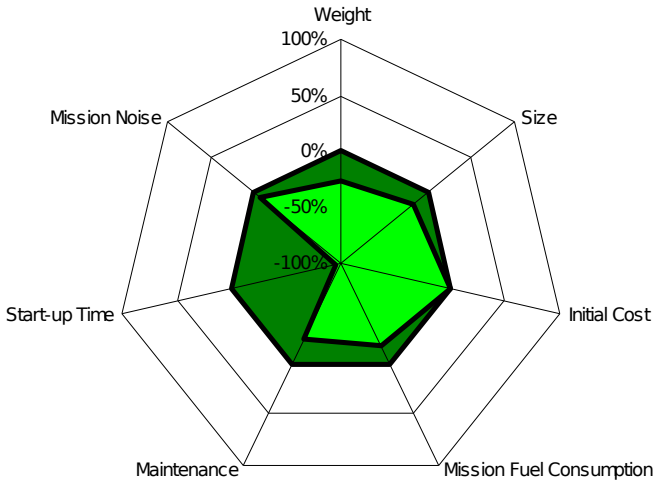
- The standard internal combustion engine is unique in its ability to start quickly and respond to transient loads.

- All diesel fueled power generation technologies other than internal combustion engines will require stored energy in order to maintain acceptable transient output performance.

- Advanced term commercial mobile power systems use a hybrid power source with batteries

Variable Speed Diesel Genset





Pro

- Higher power density
- Improved fuel consumption at partial lo
- Quieter operation at partial loads
- Less maintenance issues at light loads

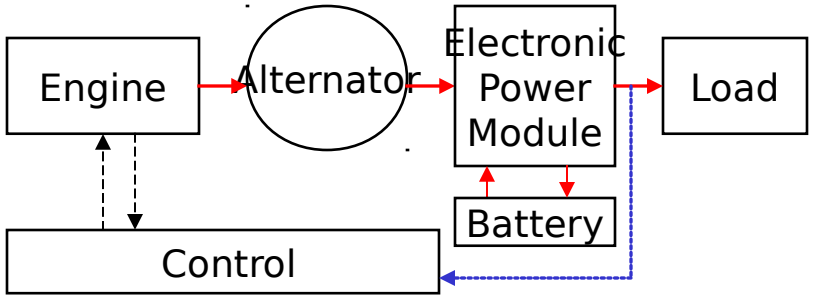
Con

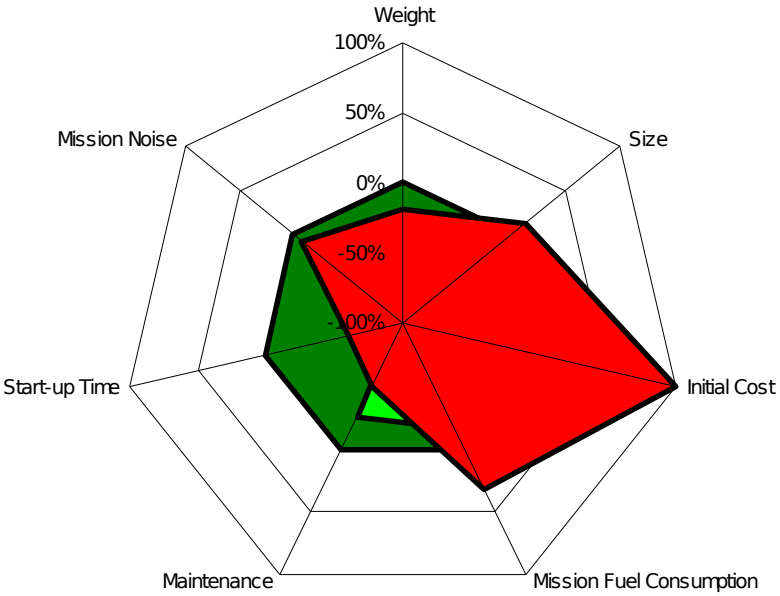
- Reduction in step load response w/o stored energy

Conclusion

- Well suited to Military mobile and AUX power

Microturbine





Pro

- Multi fuel tolerant
- quiet, light weight
- no light load operation issues
- Very little maintenance

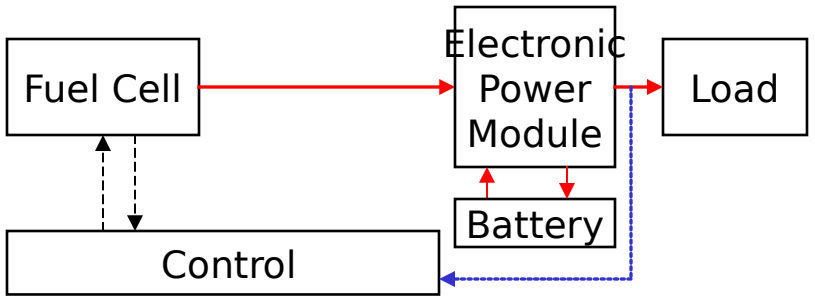
Con

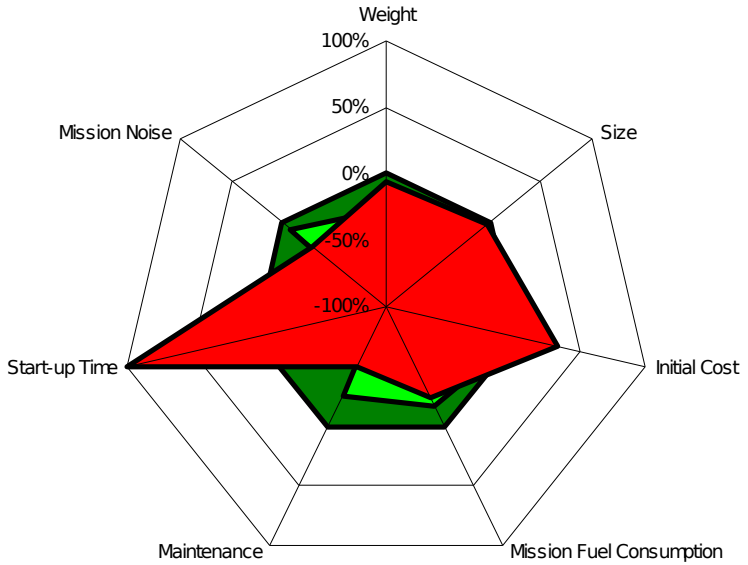
- Poor fuel consumption (future improvements using ceramics possible)
- Slow startup (over two minutes)
- Poor step load response requires battery hybrid
- complexity
- High initial cost

Conclusions

- Best suited for continuous duty applications using heat recovery
- Not well suited for mobile power generation applications

Fuel Cell





Pro

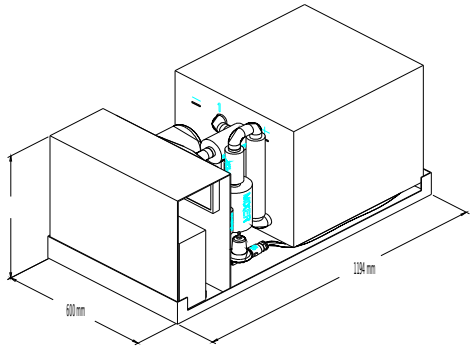
- Good part load fuel consumption
- Low noise
- Lower maintenance

Con

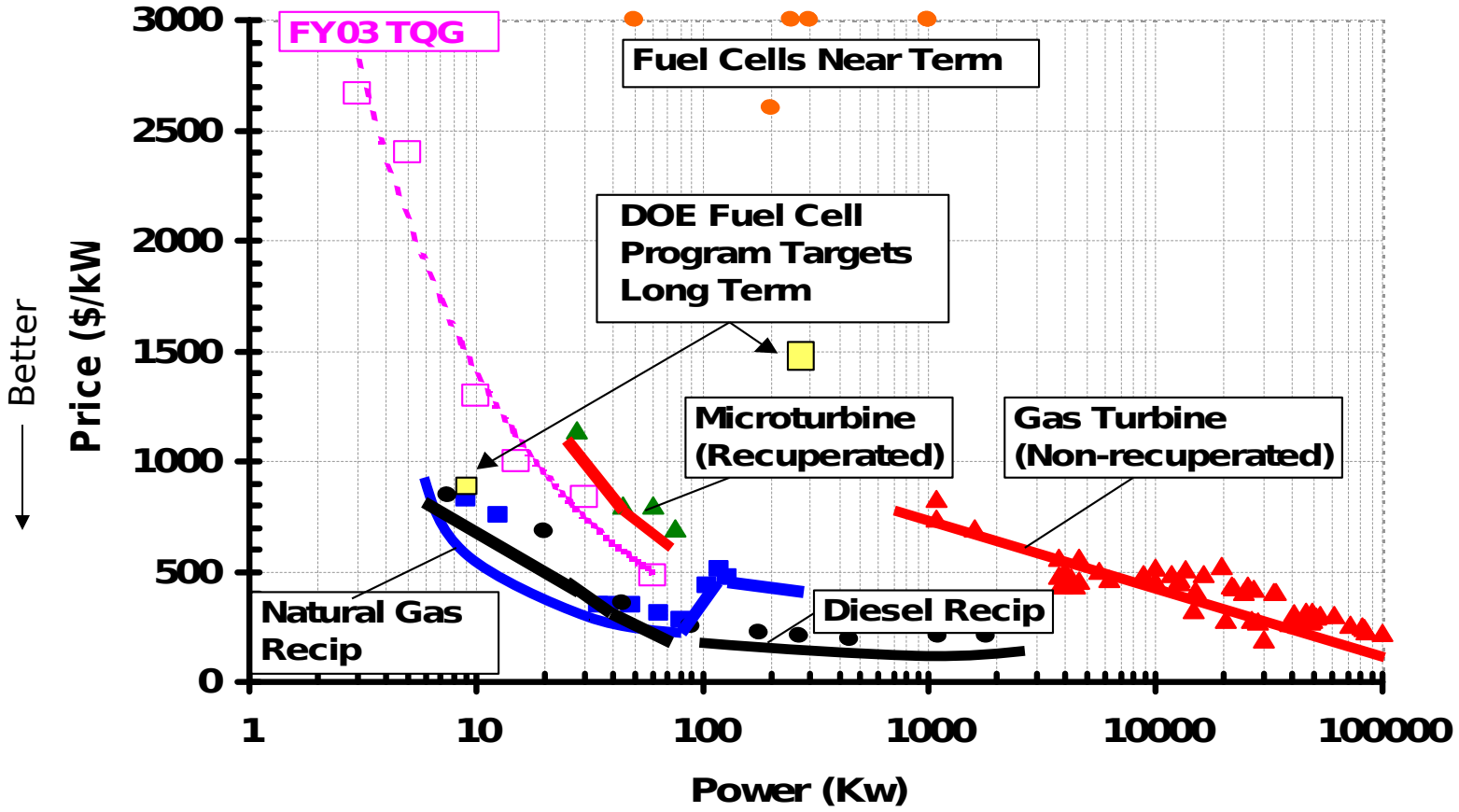
- Slow start up (over 15 minutes)
- Slower step load transient response requires battery hybrid system (power density issue)
- Lower inherent robustness to abuse and environment

Conclusions

- Highest potential to displace diesel engine gensets in mobile applications
- Start up time and other limitations will require modification of current performance requirements



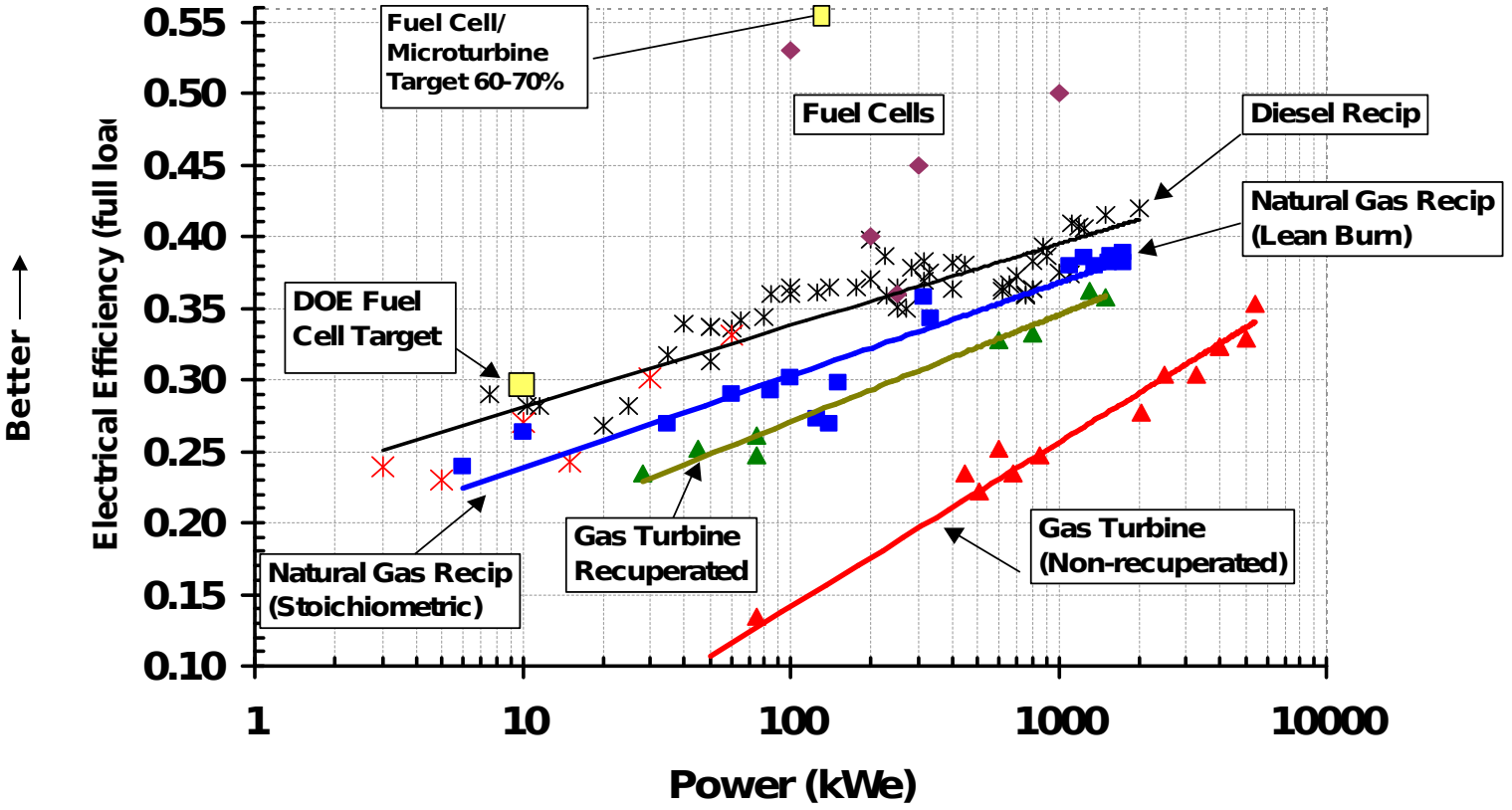
Cost/kWe vs. Power



- High fuel cell costs will start falling falling as commercial volumes begin to rise in the 2010 time frame.

Thermal Efficiency Vs. Technology

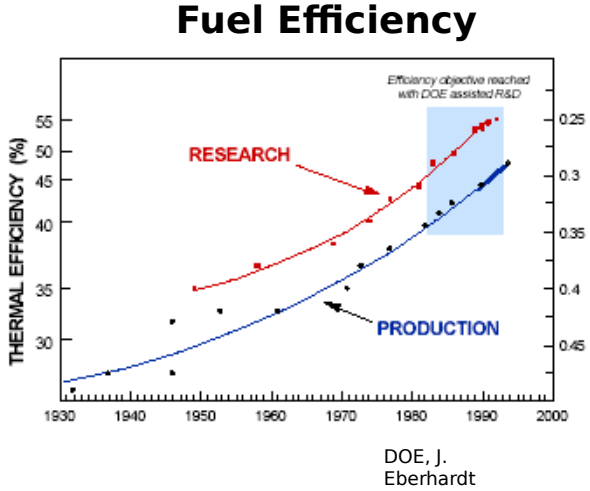
Power Generation



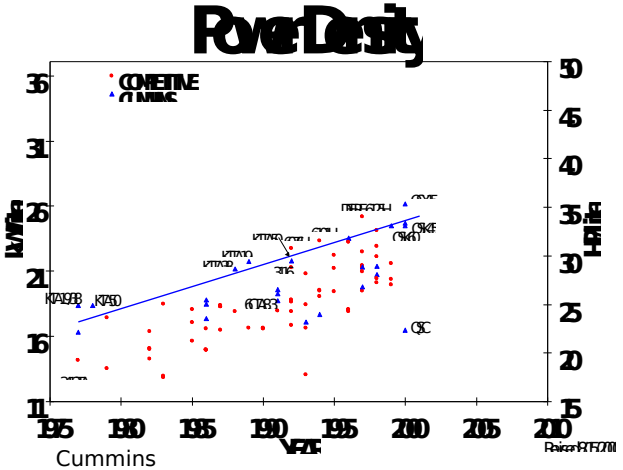
- The efficiency gains for fuel cells are more significant in larger stationary configurations

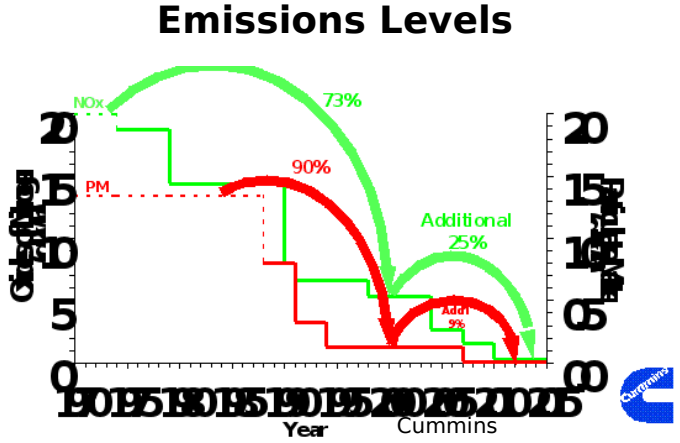
Diesel Engine Technology- A Moving Target

- The investment by DOE and industry in diesel engine technology will remain high for the forseable future
- It is becoming evident that light trucks and eventually passenger cars will be moving to diesels to achieve fuel economy
- The performance levels of diesels will continue to be a moving target for ot



DOE, J. Eberhardt





Areas of Continued Diesel Engine R&D and Performance Improvement

	Areas of Improvement				
Technology	Power Density	Fuel Economy	Noise	Emissions	Light Load Maintenance
High Pressure Injection		X		X	X
Injection Rate Shaping			X		
Variable Injection Timing	X	X	X	X	X
Variable Valve Timing	X	X		X	
Turbocharging Technology	X	X			X

Attributes of fuel cell technologies

Technology	Size	Eff. gasfuel	Operating Temp C	Maturity	COST 5-8 yr	FEATURES	ISSUES
PEM Ballard	< 100KW	36% 28% sm.	20 - 120 C%	medium	high	fast response	complex reformer
Phosphoric Fuel Cells Int'l	>100KW	40%	160 - 650 C	high	very high	mature	expensive
Carbonate FuelCell Energy	>100KW	50%	600 - 650 C	medium	high	efficient	low density therm.cycle
Solid Oxide Westinghouse SOFCo	5-1000KW	50% 30% sm.	900 - 1,000 C	low	high	efficient	maturity start time

Highest potential for small mobile power

Mobile Fuel Cell Development

- Minimum DOE R&D development program goals for 3 – 10 kW mobile fuel cell systems are modest

Year	2006	2008	2010	2011
Solicitation Ref.	(1)	(2)	(1)	(2)
Efficiency	25%	30%	35%	30%
Number of starts	20	50	400	100
Durability	1000 hr	1500 hr	5000 hr	5000 hr
Start up time	30-40 min		15-30 min.	

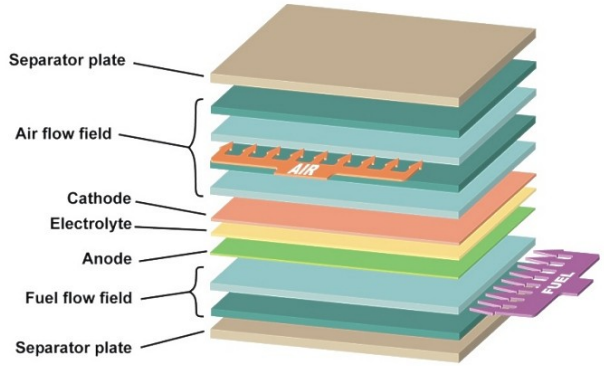
(1) DOE APU Solicitation DE-PS36-03G93000
(2) DOE SECA Solicitation DE-PS-PS26-00NT40854

- Progress by development teams indicate that commercialization is over several years away.
- The development of fuel cells to DOD requirements will likely follow commercial introductions by three years.
- It is appropriate for the DOE to support fuel cell R&D to gain a focus on unique military applications, e.g. fuels, ruggedness, performance.

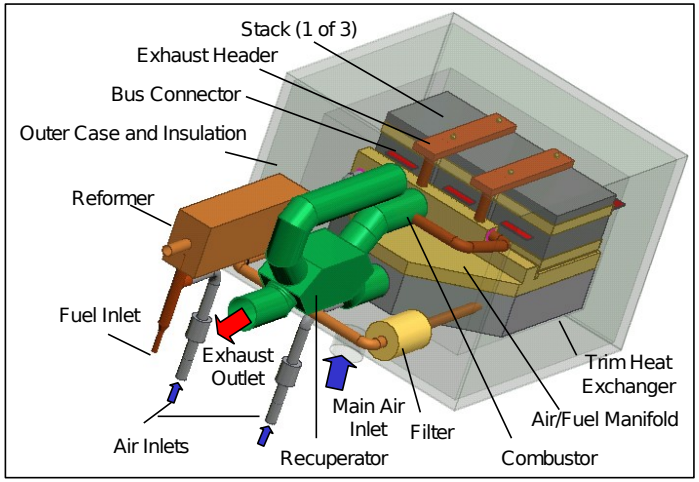
Cummins DOE SECA Fuel Cell Program

- DOE awarded Cummins $75M as part of a 10 year cost shared development program to develop a 10 KW SOFC fuel cell system
- Other contract awards to Delphi, GE, Siemens Westinghouse, FuelCell Energy, and Acumentrics
- Identified commercial markets include:
  - Recreational Vehicles
  - Commercial vehicles
  - Telecommunications
- Base technology is scalable to
  - larger units over 200 KW.

Co-fired Ceramic Stack



Sub System Assembly

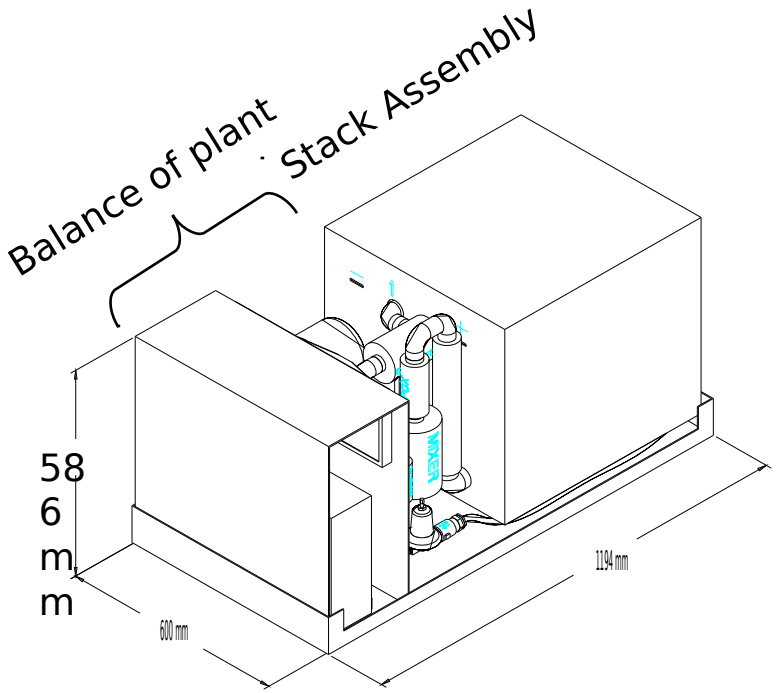


Development

- Program management
- System logic controls
- Power inverter control
- Blowers and Temperature modulating controls
- Fuel system
- System packaging

- SOFC stack
- Partial oxidation reformer
- H[illegible]rator
- Hot box packaging

clean energy for the world



Summary Assessment of Fuel Cells or DOD Mobile Power

- The initial DOD application for fuel cells will likely be for battery replacement below 1kW
- The requirement to use DOD diesel derivative fuels for larger mobile power is driven by the need for fuel compatibility with associated vehicle fuels
- Difficulties reforming high sulfur fuels for fuel cells will have to be addressed
- Fuel cells offer noise and fuel efficiency benefits, but will have start up time and initial robustness limitations
- Significant R&D funding by the DOE will help make fuel cells a reality with commercial markets emerging first

Conclusions

- It is likely that he next generation TQ mobile power will be variable speed diesel engine powered
- Fuel cells will be an important future power source for the military
- It is likely that fuel cells and diesel engine gensets will coexist to meet a variety of mission needs
- Cummins Power Generation is committed to the development of fuel cells for key commercial and military markets

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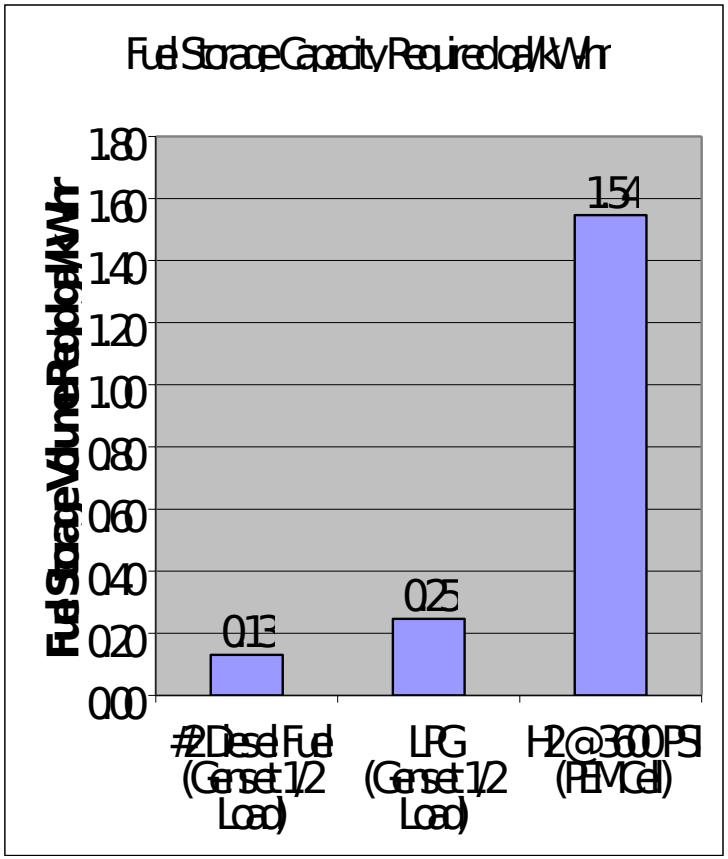
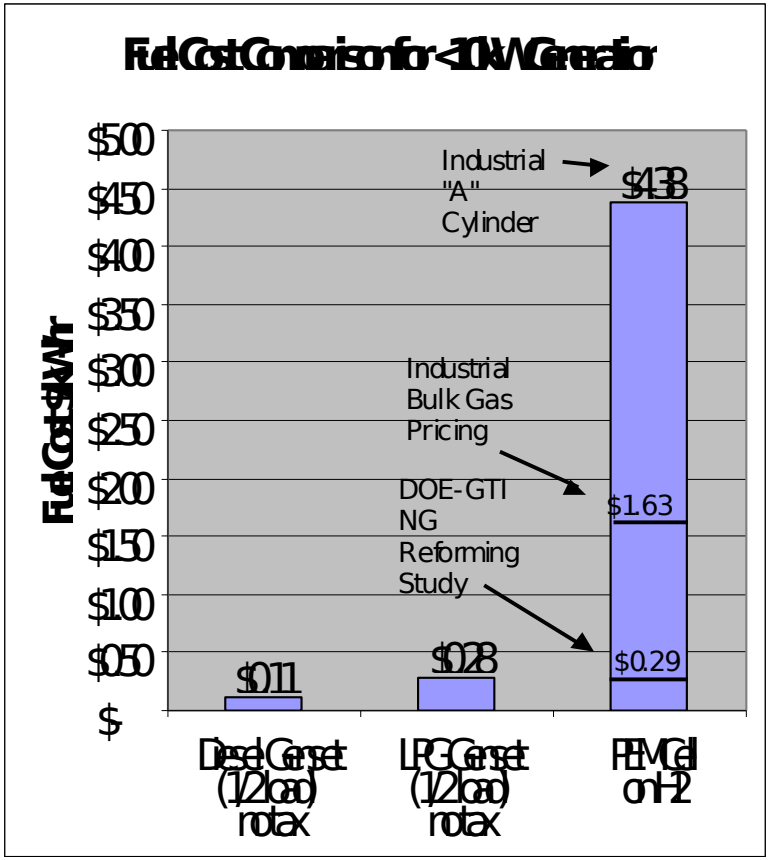
Fuel Storage Volume and Cost Comparison





Power Generation

Emissions Standards and Controls Technology Options